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GROUNDWATER, CLIMATE CHANGE AND CONFLICT:

Empirical Evidence from Africa *

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Abstract

Groundwater plays a critical role in supporting economic activities in Africa, particularly in regions affected by climate change-induced water scarcity. This study examines the economic implications of groundwater in relation to conflict dynamics in these regions. We employ a comprehensive dataset covering the period from 1997 to 2021, which includes information on conflict events and groundwater availability. By utilizing cross-sectional and temporal analyses, we investigate the relationships between groundwater depth, climate change, and conflict occurrences. Our findings indicate that areas with a higher share of shallow water – i.e., more accessible groundwater – are more prone to violence, with a heightened effect observed in the 2010s. Furthermore, shallow water has a larger impact on low-intensity conflict events and those related to water and sexual violence. We also highlight the role of local actors and within-cell inequality in water access as significant drivers of conflict. The findings underscore the need for developing equitable water management strategies to mitigate conflict and promote sustainable development in Africa.

Keywords: Groundwater; climate change; water scarcity; conflict, Africa

JEL Codes: O13; D74; Q54; Q25; Q32; Q34

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1 Introduction

Groundwater plays a crucial role in supporting various human activities in Africa. Rainfall serves as a vital water source for agriculture, livestock ponds, and drinking water through rainwater harvesting. However, in regions where climate change has led to decreasing rainfall, increasing temperature, and increased climate variability, groundwater – i.e., water stored beneath the Earth's surface in aquifers – is becoming increasingly important. Yet, although groundwater can be used for agriculture, its use remains limited to less than 1% of the agricultural area in sub-Saharan Africa (SSA, hereafter). Instead, in SSA, groundwater plays a crucial role in supplying drinking water to rural communities and meeting the water needs of transhumant pastoralists and their livestock.

The increasing economic significance of groundwater given continental climate change prompts the question of whether its presence in regions specifically affected by climate change leads to a *reduction* or *escalation* of conflict. Two countervailing effects come into play. First, the scarcity of water resources resulting from climate change may diminish conflict in areas where accessible groundwater is available, known in the conflict literature as the *income effect*. Groundwater serves as an alternative water source, lessening reliance on surface water or rainfall. In other words, when surface water becomes scarce, communities and nations can potentially turn to groundwater reserves as a substitute. This alternative source mitigates some of the pressure and tension arising from climate change-induced water scarcity, which often contributes to conflicts. However, the rising value of groundwater, similar to other natural resources, may increase conflict in these regions, termed the *prize effect*. Water scarcity exacerbates existing tensions and triggers conflicts over access to this vital resource. Competitions and disputes emerge among communities and nations facing limited water supplies, potentially resulting in conflicts at different levels, ranging from local to international. Considering imperfect water markets and competition for scarce resources, the prize effect may outweigh the income effect, leading to heightened conflict.

We investigate such effects by using a data set in which the units of analysis are cells of 0.5×0.5 degree latitude and longitude, which correspond to $\approx$ 55 km$\times$55 km at the equator, covering the entire African continent from 1997 to 2021. For every cell$\times$year unit, we gather two types of information: (i) on conflict events; and (ii) on the availability of groundwater. Specifically, we use the *Armed Conflict Location Events Data* (ACLED), which offers comprehensive details regarding the date, location, and type of conflict events. We then use geolocalized data at a resolution of 0.05×0.05 degrees for groundwater levels (Bonsor and MacDonald, 2011), allowing us to compute the share of 0.05×0.05 degree pixels contained in different categories of water depths in each cell of 0.5×0.5 degree latitude and longitude (0-7, 7-25, 25-50, 500-100, 100-250 and 250+ meters). Informed by the literature, we use the time-invariant share of the cell with groundwater depth between 0 to 50 meters as a baseline measure to capture *shallow water* (i.e., groundwater accessibility) at the cell level.

To uncover the different aspects of the research question, we implement two main empirical analyses. First, we explore how the relationship between conflict and groundwater evolved over time given the impact of *global* climate change, which affected the entire continent during the same period. Second, we study how the association between conflict and groundwater in areas experiencing *local* climate shocks – i.e., short-term deviations in their climate – or long-term climate change – i.e., long-term deviations.

Across the analyses, we find that cells with larger shares of shallow water are on average *more* prone to violence, with an acceleration of the effect in the 2010s. Quantitatively, on average over the period 1997-2021, one standard deviation increase in shallow water is associated with a 0.16 standard deviation increase in conflict incidence. Shallow water has differential impacts on the type of conflict, as the effect is more pronounced for *low-intensity* (i.e., more localized) conflict events (e.g., protests and riots). Quantitatively, a one standard deviation increase in shallow water is associated with a 0.25 standard deviation increase in *low intensity* violence vs. a 0.06 standard deviation increase in *high intensity* violence (e.g., battles, violence against civilians). We also highlight the significant role of local community actors in these groundwater-related conflicts. Furthermore, we demonstrate that spatial (within-cell) inequality in groundwater access also plays a role in driving conflict in the post-2010 period.

Looking at *local* climate shocks delivers also interesting features. In groundwater-rich areas, a one standard deviation increase in local temperature leads to an increase in conflict from a 0.071 standard deviation to 0.276 standard deviation. In a counterfactual exercise, we estimate the contribution of the upward trend in local temperature. In cells without shallow water the absence of positive trend in temperature the probability of observing conflict would have been 1% lower. But, in cells with a proportion of shallow water larger than 50%, the likelihood would have been reduced by 7%. Interestingly, in cells without water inequality in the groundwater access, the probability of observing conflict would have been 1% lower. Conversely, for the highest percentile of water inequality in the groundwater access, the likelihood of observing conflict would have been reduced by 14%.

Furthermore, we highlight to potential mechanisms. First, the prize effect is likely increased for livestock herder communities as water is an essential production input for livestock rearing. In addition, nomadic livestock communities tend to be more mobile, thus being able to reach water points more easily, and also tend to be more weaponized, due to livestock theft. We do find stronger effects of climate change in groundwater-rich areas in regions specialized in pastoral activities or farming areas located at the edge of pastoralist regions where livestock herders often relocate during the dry season. Second, areas with stronger state capacity could be better able to control conflict. At the same time, groups may fight and/or lobby for controlling for state resources, which could lead to more conflict there. The two effects thus appear to cancel each other. On average, we do not find evidence that national or local state capacity mitigate the overall effect on conflict incidence. But, interestingly, the lack of overall effects hides strong positive effects on low-intensity conflicts and strong negative effects on high-intensity conflicts. Indeed, areas where the state is stronger are better able to control violent conflict. Such areas also respond more to lobbying due their importance in the national political process. Overall, the findings highlight the importance of understanding local dynamics and contextual factors when analyzing the effects of climate change on violence. By acknowledging the agency and actions of local actors, policymakers and stakeholders can develop targeted interventions and strategies to address the underlying drivers of conflict in affected regions.

Contribution to the literature This research complements two strands of the literature, on the effect of climate change on development and conflict, and on the water-conflict nexus. Given the multiple consequences of changing climatic conditions, the former literature has studied the impact of climate change on multiple topics such as labor productivity, poverty, migration or health. Thompson et al. (2010) provide evidence of negative effects on crop productivity, land degradation as well as increased malnutrition due to climate change. Meierrieks (2021), reveals that short-term weather shocks and long-term climate change, through rising temperatures particularly, detrimentally affect health, with poorer nations bearing a disproportionate burden. Blakeslee et al. (2020) shows how agricultural income strongly declines for households following the drying up or loss of their first borewell, which directly contributes to increased poverty.

We contribute to an extensive literature studying the causes of conflict, focusing on the role of natural resources (Lujala et al. (2005), Lu and Yamazaki (2023), Schoderer and Ott (2022), Berman et al. (2017a)), inequality (Bartusevičius (2014), Østby (2013), Cramer (2003)) or ethnic divisions (Manotas-Hidalgo et al. (2021), Kanbur et al. (2011), Blattman and Miguel (2010)).The role of climate change in the causes of conflict has received particular interest over the recent years. Hsiang et al. (2013) find from a synthesis of this literature that variations from precipitation and temperature patterns consistently raise the likelihood of conflict. Van Weezel (2020) explores issues of long-term climate change on conflict risk in Africa, demonstrating a significant correlation between rising temperatures and heightened conflict risk. Breckner and Sunde (2019) reveals a positive effect of temperature extremes on conflict incidence in Africa, with stronger effects observed in regions facing more severe and prolonged extremes, higher population density, lower agricultural productivity, and more pronounced land degradation. Barnett and Adger (2007) argue that climate change is anticipated to diminish states' capacity to provide opportunities and services vital for livelihood sustainability, as well as limiting access to and quality of natural resources, thereby undermining human security which could lead to violent conflicts. The role of natural resources in this climate change-conflict nexus is often studied through agricultural income shocks due to climate change (Iyigun et al. (2017), Miguel et al. (2004)). Von Uexkull et al. (2016) find that the onset of droughts appears to have minimal impact on the propensity of groups to initiate military confrontations with the state. Nonetheless, among agriculturally dependent and politically marginalized groups, the occurrence of localized drought conditions significantly amplifies the likelihood of sustained violence. (See Sakaguchi et al. (2017) for an extensive literature review.)

Our paper contributes in particular to the literature on the water-conflict nexus. Recent quantitative research investigates the effects of water scarcity and drought on conflict. Devoto et al. (2012) highlight the escalation of disputes, specifically those related to irrigation water during water shortages. Sekhri (2014) supports this finding, reporting a 25% increase in self-reported disputes over irrigation water during water scarcity episodes. Detges (2016) finds that regions with limited access to improved water sources are more prone to experiencing drought-related communal violence. This latter result is supported by Döring (2020) who investigates the relationship between water scarcity, local water access and communal violence, emphasizing the influence of state presence, adaptation opportunities, and short-range migration as contributing factors to the relationship. Indeed, migration emerges as a coping mechanism in response to climate change induced water scarcity (Jedwab et al., 2023), and Fishman et al. (2017) observe increased migration, particularly among young males, driven by lack of water access. Couttenier and Soubeyran (2014) find a weak positive link between droughts and civil war in Sub-Saharan Africa. In the same geographic setting, Harari and Ferrara (2018) find that conflict incidence is impacted by negative weather shocks during the growing season, and that conflict incidences spreads in time and across space. Almer et al. (2017) find that droughts tend to escalate small-scale social conflict, particularly in Sub-Saharan African areas with low water supply. Unfried et al. (2022) link climate-induced water mass changes, such as increased evapotranspiration and drought-induced reduction in water mass, to social conflict. They note that a reduction in water mass within a region significantly increases the likelihood of social conflict. Close to our paper, Detges (2014) highlights a consistent pattern of pastoralist violence in the dry region of northern Kenya, with violence disproportionately occurring in close proximity to well sites as well as areas experiencing higher rainfall.

In summary, the literature reviewed showcases the interconnected nature of climate change and water scarcity and their multifaceted impacts on economic development, poverty rates, migration, and conflict. Understanding these relationships is crucial for designing effective strategies to address and mitigate the challenges posed by climate change, and water scarcity. In addition to the existing literature, our study extends the understanding of the relationship between climate change, water scarcity, and conflict in different ways. Firstly, we consider present-day conflicts, encompassing both violent and non-violent disputes over water resources, regardless of whether they result in fatalities. This broader scope provides a comprehensive understanding of the range of conflicts associated with water scarcity. Moreover, we introduce the concept of within-cell inequality in access to groundwater. We focus on the variations in groundwater accessibility within specific grid cells. This approach allows us to capture the nuances and disparities in water availability and its impact on conflict within localized areas. Furthermore, we emphasize the importance of incorporating local temperature trends in addition to global temperature rises when analyzing the effects of climate change. By considering specific temperature changes experienced at the local level, we gain a more precise understanding of the relationship between climate-induced water scarcity and social conflict. This nuanced approach enables us to assess the localized impacts of temperature changes on conflict dynamics.

In the following section, we describe the data and summary statistics. Section 3 contains the economic strategy, as well as the baseline results and a number of sensitivity exercises. In Section 4, we investigate different mechanisms and highlight hotspots of violence. The last section concludes.

2 Data

In this section we summarize the main variables and sources used in our baseline estimations as well as some empirical exercises to corroborate some of our identifying assumptions.

2.1 Unit of analysis

Our units of analysis are cells of size 0.5×0.5 degrees (≈ 55×55 km at the equator), covering the entire set of African countries (N = 10,310 cells). Most of the data we use throughout the paper are available at a more disaggregated level. For this reason, we aggregate the data in order to generate a dataset at the *cell-year* level. We use this level of aggregation rather than administrative boundaries in order to ensure that our unit of analysis is not endogenous to conflict events. We assign a country to each cell based on the end-of-period boundaries.[1]

2.2 Data Sources

Conflict data. We use conflict event data from the Armed Conflict Location and Event Dataset (ACLED) which contains information on conflict events in all African countries from 1997 to 2021 (`https://acleddata.com/`).[2] Crucially, these data contain information about the date, GPS location, nature of events, as well as who are the actors that participate to each single events.[3] Events are compiled from various sources, including press accounts from regional and local news, humanitarian agencies, and research publications. The dataset contains information on 281,311 distinct violent events. To ensure high geographical precision, we excluded events that were coded as "part of a region", "region", or "country", leaving us with 211,474 observations after removing exact duplicates in the data. In terms of nature of the events, we consider battles, violence against civilians, protests, riots, and remote violence. We define a measure of *low-intensity* violence that encompasses protests and riots, while our measure of *high-intensity* violence includes battles, violence against civilians, and remote violence. We also classify the type of violence based on the spatial dimension of the actors, distinguishing between *local actors* such as protesters, rioters, and identity militias, and *non-local* actors, including external forces, political militias, rebel groups, and state forces.

Groundwater availability. Unfortunately, granular data on groundwater depth is not available in Africa. To overcome this issue, we make use of Bonsor and MacDonald (2011)'s data, which employs a modeling approach to recreate localized data on groundwater depth in Africa. Their model incorporates geological maps (USGS) as well as high-resolution rainfall data. Data are creating following three primary rules: (i) as rainfall decreases, the depth to groundwater increases; (ii) basement rocks play a significant role, particularly in semi-arid regions; and (iii) if an area is located within 5 km of a river, the depth to groundwater is considered to be very shallow (less than 7 meters). The model's predictions are validated using external groundwater depth information obtained from international organizations and NGOs involved in relevant projects (most often on the construction of wells). The raw map contains 0.05×0.05 degree pixels, which is finer than our unit of analysis. We then estimate for each cell of 0.5×0.5 degrees the share of pixels contained in

[1] Online Appendix Figure OA1.1 shows the countries, regions, and cells used in the analysis.

[2] Download on June 2th 2022.

[3] The data are widely used, see for instance Berman et al. (2017b); McGuirk and Burke (2020); Berman et al. (2021); Couttenier et al. (2024).

each category of groundwater depth (0-7, 7-25, 25-50, 50-100, 100-250, 250+ meters). Lastly, we will investigate the robustness of our results to directly including controls for aridity and rainfall.

The costs associated with digging and pumping groundwater rise exponentially as groundwater depth increases (Uhl et al., 2009; Bonsor and MacDonald, 2011; MacDonald et al., 2012). Up to a depth of around 7 meters, suction pumps can be used effectively (Sekhri, 2014). Beyond this depth, lift pumps with reciprocating action become necessary. Manual drilling is feasible until a depth of 25 meters, after which it becomes more challenging. Hand-operated lift pumps can be utilized up to a depth of 50 meters, with an estimated cost of approximately 500 USD. For depths ranging from 50 to 100 meters, water is not accessed easily by hand pumps, and rotary action pumps are typically employed (MacDonald et al., 2012). Depths exceeding 100 meters require deep wells, machine-driven rigs (costing over 100,000 USD), and engine-driven rotary action pumps.

Informed both by anecdotal evidence and the literature, we compute the share of each cell with groundwater depth ranging from 0 to 50 meters as our baseline measure to capture shallow water at the cell level. In the appendix, we show that results hold: (i) using the share of the cell with groundwater depth ranging from 0 to 25 m; and (ii) using several categories (0-7, 7-25, 25-50, etc.).

In addition, our measure of within-cell inequality is a fractionalization index $Frac_c$ capturing the degree to which a cell c is split into distinct groups:

$$Frac_c = \sum_{d=0}^{250+} (share\, groundwater_{dc} \times (1 - share\, groundwater_{dc}))$$

where, $share\, groundwater_{dc}$ is the share of groundwater of depth d in cell c; and $d \in$ (0-7, 7-25, 25-50, 50-100, 100-250, 250+ meters). The more diverse the cell is in terms of groundwater levels, the higher the index of fractionalization is, which represents a higher degree of within-cell inequality.

Other. Additional data sets used include data on wells, climate characteristics, population density, nutrient availability, malaria prevalence, transhumant pastoralism, and state capacity. Data on wells was collected from Open Street Map by retrieving the location of structural facilities to access ground water, created by digging or drilling.[4] The data provides details such as the number and attributes of wells. As this information is self-reported, it may suffer from reporting bias, especially in conflict-prone areas. This prevents us from using them as baseline measures. Climate data was obtained from the widely used Climatic Research Unit gridded Time Series dataset (CRU-TS) at the University of East Anglia, which covers the period from 1901 to 2022 (Harris et al. (2020); resolution: 0.5×0.5 degrees). We also make use of data from the World Bank Climate Change Knowledge Portal (CCKP) on climate prediction from 2023 to 2100 (resolution: 1×1 degrees). We use Köppen maps (Rubel and Kottek (2010)) categorizing cells of 0.5×0.5 degrees into major climate types based on temperature and precipitation patterns. This information provides a framework for comparing different climates within our spatial coverage. We measure nutrient availability using data from Berman et al. (2021) who retrieve data from the Harmonized World Soil Database to

[4]The data was collected using the tag *"man_made = water_well"* and retrieved on December 15th, 2022.

quantify the natural fertility of soils based on their nutrient content. Second, we rely on data from McGuirk and Nunn (2020) to identify transhumant pastoral societies to account for the presence of nomadic communities engaged in livestock herding in Africa. To add to this analysis, we use data from Eberle et al. (2020) to account for locations with mixed settlements populated by both herders and farmers. We use spatial fine-grained information on malaria prevalence which relies on projections derived from survey data on malaria prevalence collected from different locations in Sub-Saharan Africa (Cervellati et al., 2017). Finally, to approximate local state capacity we make use of the measure constructed by Agneman et al. (2022) using geocoded survey data on local state presence, which is predicted and extrapolated through a machine learning model (resolution: 0.05×0.05 degrees).

2.3 Summary statistics and visualization

Table OA1.1 displays the descriptive statistics for the cumulative cross-sectional variation from 1997 to 2021 (columns 1 to 3, unit of observations: cells) and for the panel variation (columns 4 to 6, unit of observations: cell$\times$year). On average, the proportion of shallow water (0-50 meters) is 58%. Half of the cells has a proportion of shallow water that is larger than 95% and 30% has no shallow water. Over the period, while 45% of cells experienced at least one violent event during the period, this figure conceals a significant variation. Cells with more than 95% of shallow water were three times more likely to face conflict compared to those with no shallow water (62% vs. 21%). The difference in conflict incidence between cells with more than 95% shallow water and those with no shallow water persists regardless of the intensity of the conflict (low and high intensity) or whether it is carried out by local or non-local actors.

At the cell$\times$year level, the unconditional probability of violence is at 10%. Again, cells with a high percentage of shallow water are the most exposed to violence. The probability of conflict is 14% for cells with 95% of shallow water, compared to 4% for cells with no shallow water. This figure persists regardless of whether the violence is low-intensity or high-intensity, or whether it is carried out by local nor non-local actors. Finally, Figures 1 to 4 provide a visualization of the spatial dispersion of conflict events since 1997, groundwater depth, our measure of shallow water, and our measure of groundwater inequality.

2.4 Validation of the Shallow Water Measure

We now corroborate one of the paper's crucial assumption, namely that cells with a large share of shallow water are also more likely to have a larger number of wells. Doing so, we estimate the following equation:

$$Wells_c = \alpha_t Shallow\,Water_c + \gamma_t Official\,record_c + \varepsilon_c \qquad (1)$$

where $Wells_c$ measuring either the number of wells or the share of each type of wells in cell c. The information contained in the data set allows us to distinguish the type of wells, hence the technology used. We distinguish between wells using only a rope and a bucket, wells with a manual pump, and wells with a powered pump. Then, we compute the share of a given type

Figure 1: Conflict Events 1997-2021

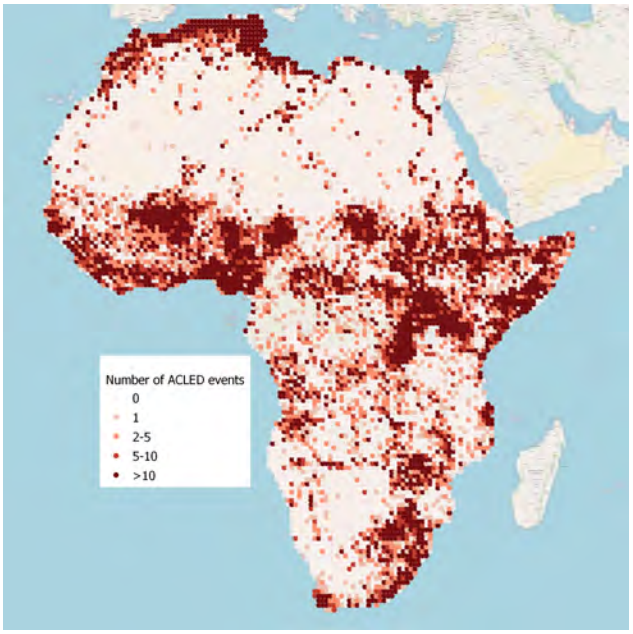


Figure 2: Groundwater Depth Categories

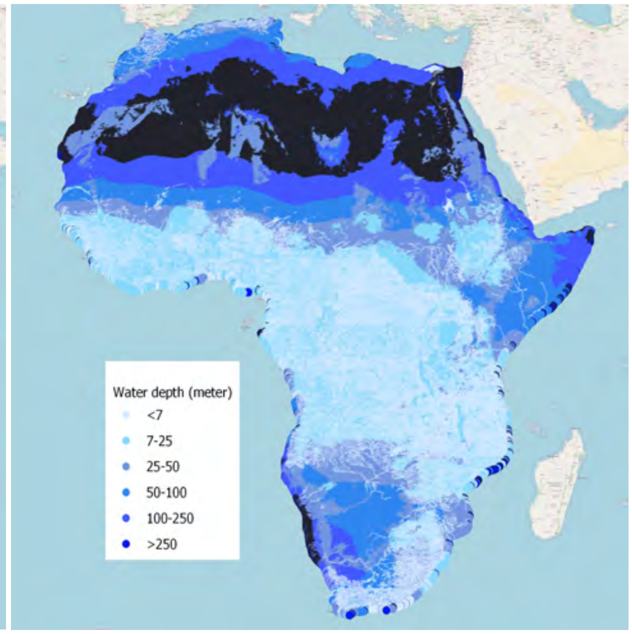


Figure 3: Share of Shallow Water 0-50m

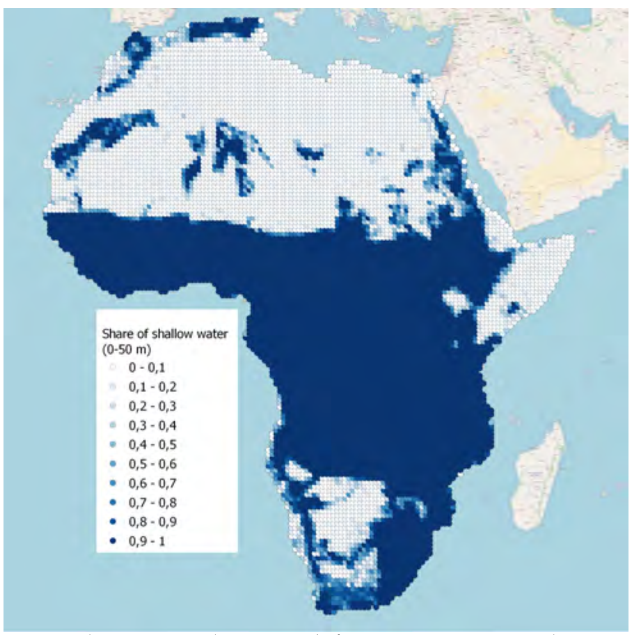
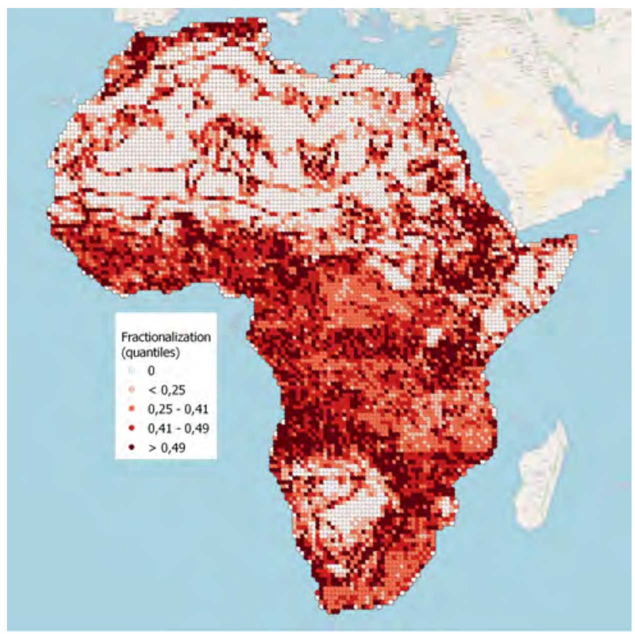


Figure 4: Fractionalization Index (0.5×0.5)



Note: The map on the upper left corner represents the cumulative number of recorded ACLED conflict events in Africa over the period 1997-2021. The map on the upper right corner represents the data from Bonsor and MacDonald (2011) with the different groundwater levels at pixel level. The map on the bottom left corner is a map of the share of 0 to 50 meters deep groundwater in Africa for each cell. The map on the bottom right corner is the representation of our measure of fractionalization i.e the within cell inequality in access to water.

of wells p over the total number of wells in the cell c. We also control for whether the reporting of the well's location in Open Street Map comes from an official source ($Official\,record_c$) such as ONG records. The variable $Shallow\,Water_c$ is our standard measure of groundwater availability ranging from 0 to 50 meters deep.

Table 1: Groundwater Depth and Type of Wells, Cross-Section

		Pump Type		
Panel A	(1)	(2)	(3)	(4)
Dep. Var.: Number of	Wells	Bucket	Manual	Powered
Shallow water share	–0.10	0.01	0.81**	0.20
	(1.41)	(0.07)	(0.38)	(0.16)
Mean	5.63	0.41	0.76	0.14
Obs.	10310	10310	10310	10310
Country FE	Yes	Yes	Yes	Yes
Panel B		(2)	(3)	(4)
Dep. Var.: Share of		Bucket	Manual	Powered
Shallow water share		0.76**	1.55**	–0.83
		(0.32)	(0.68)	(0.77)
Mean		0.71	3.13	0.81
Obs.		10310	10310	10310
Country FE		Yes	Yes	Yes

Notes: Shallow water share refers to the share of 0 to 50 meters deep groundwater, from 0 to 100. Column (1) is the overall number of wells recorded in a cell. Columns (2), (3) and (4) give additional details on the latter by identifying the type of pump: bucket type, manual pump, and powered pump, respectively. In panel A, the dependent variable is the number of said wells. In panel B, the dependent variable is the share of each type of pumps in the total number of wells. Country fixed effects are added in all regressions. Standard errors clustered at the first administrative level in parentheses. * Significant at 10%, ** significant at 5%, *** significant at 1%.

As already discussed in MacDonald et al. (2012), we find that cells with more shallow water exhibit a higher concentration of wells (see Table 1). The analysis demonstrates a significantly greater abundance of manual pumps in shallow water areas. Furthermore, there is a higher proportion of bucket-type wells and manual pump wells in these shallow water cells. Conversely, powered pumps are less present in cells with high levels of shallow water. These findings align with the cost considerations associated with different water depths, emphasizing the shift towards lift pumps and machine-driven rigs for deeper wells. Reassuringly, the results confirm the validity of our proxy measure for shallow water.

2.5 Identifying variation

The analysis of variance within the data set reveals notable variations in the availability of shallow water at different geographic levels. The share of variance attributed to shallow water within the country level is 37%, indicating significant variability in groundwater availability within countries. Similarly, at the admin-1 level ("regions" or "provinces"), the share of variance associated with shallow water is 17%. Furthermore, at the admin-2 level (the administrative unit below the region), the share of variance related to shallow water is 12%. These findings indicate that while a significant portion of the variation is explained by differences between countries, regions, and subregional units, there is still substantial variation within these administrative divisions. This suggests that incorporating more spatially refined fixed effects can provide additional insights into the relationship between groundwater availability, climate change, and conflict.

3 Econometric Strategies and Results

To explore the various dimensions of the research question, we conduct two main empirical analyses. First, we examine the evolving relationship between conflict and groundwater, taking into account the influence of global climate change, which impacted the entire continent during the same period. Second, we delve into the specific connection between conflict and groundwater in regions that experienced localized climate shocks or long-term climate change.

3.1 Effects of Global Climate Change

We estimate the effect of *global* climate change over time – the fact that the climate has worsened across almost all African regions – on the relationship between groundwater accessibility and conflict. Our assumption is that, with continent-wide climate change, the importance of groundwater availability in relation to conflict has increased, leading to a possibly higher incidence of conflict in groundwater-rich areas over time.

Empirical strategy. We estimate the following equation:

$$Y_{cit} = \sum_{t=1998}^{2021} \beta_t Shallow\,Water_c \times \mathbb{I}_t + \theta_c + \theta_{it} + \varepsilon_{cit} \tag{2}$$

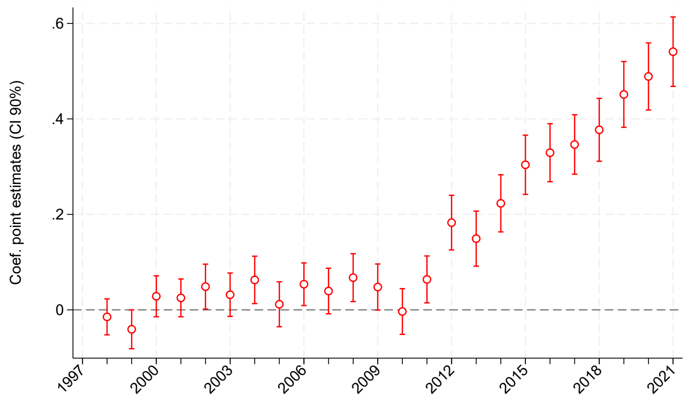
where, Y_{cit} represents the incidence of violence, encompassing all events, although we also estimate specifications using different types of such as *low-intensity* violence that encompasses protests and riots, *high-intensity* violence that includes battles, violence against civilians, and remote violence. We also classify the type of violence based on the spatial dimension of the actors, distinguishing between *local actors* such as protesters, rioters, and identity militias, and *non-local* actors, including external forces, political militias, rebel groups, and state forces.

To ease the comparison of magnitudes, we standardize the dependent variables, hence convert them to Z-scores. $ShallowWater_c$ denotes the share of the cell with groundwater availability ranging from 0 to 50 meters deep. The term $\mathbb{I}_t$ represents year dummies, allowing for the examination of the non-linear time-varying relationship between groundwater availability and conflict. Additionally, the terms θ_c and θ_{it} capture cell fixed effects and country×year fixed effects, respectively, accounting for unobserved factors specific to each cell and each country×year. We estimate equation 2 using a linear probability model (LPM) and standard errors are clustered at the cell level. Our interest lies in the set of coefficients β_t that capture the effect of groundwater availability in each specific year t, in relative to the initial reference year 1997.

Baseline results. Figure 5 displays the point estimates $\hat{\beta}_t$. In comparison to the reference year 1997, groundwater-rich cells do not display a systematically significant level of violence until 2010 (with the exception of the years 2004, 2006, and 2008). From 2011 onward, we observe a positive trend. At the end of the period, the magnitude is substantial. In comparison to the year 1997, one standard deviation increase in shallow water increases the level of violence by 0.54 standard deviation on average in 2021. Table 2 displays the results from selected non-linear combinations of $\hat{\beta}_t$. We find a quantitative significant positive average effect for the whole period 1997-2021: one standard deviation increase in shallow water is associated with a 0.16 standard deviation increase in conflict incidence (column 1). These findings suggest that variations in shallow water have a significant impact on conflict, accounting for a significant portion of the overall variation observed. In column (2), the same method is used but we differentiate the point estimates for the years before 2010 and after 2010. We observe an acceleration of the effect post-2010. In other words, cells with a large share of shallow water became more prone to violence over time, possibly as a result of accelerating climate change trends on the continent. The inclusion of the measure of fractionalization leaves the point estimates of shallow water broadly unchanged (columns 3 and 4). Interestingly, cells with a larger fractionalization index also became more prone to violence over time (column 4).

Results by type of violence and actors. The richness of our dataset on violent events enables us to delve into the intricate dynamics of how shallow water influences both different violence types and how actors respond differently over time. Figure 6 displays the results. A number of noteworthy results emerge. First, the effect of shallow water over time matters for both *low intensity* violence (protests and riots combined) and *high intensity* violence (battles, violence against civilians, and remote violence). However, the magnitude is different as a one standard deviation increase in shallow water is associated with a 0.25 standard deviation increase in *low intensity* violence vs. a 0.06 standard deviation increase in *high intensity* violence (Figure 6a). This suggests

Figure 5: The effect of shallow water over time



Notes: Yearly point estimates of $\hat{\beta}_t$, coefficient for shallow water which refers to the share of 0 to 50 meters deep groundwater, in comparison to the reference year 1997 are reported. The dependent variable is a dummy taking the value 1 if at least a conflict event is observed in the cell during the year, 0 otherwise. Cell fixed effects and country x year fixed effects are added to each regression. Standard errors clustered at cell level. 90% confidence intervals are reported.

that groundwater availability plays a more significant role in shaping more localized conflicts characterized by protests and riots, which are typically considered low-intensity forms of conflict.[5] Second, the likelihood of violence increases over time with the presence of shallow water for both *local* actors (protesters, rioters, and identity militias) and *non-local* actors (external forces, political militias, rebel groups, and state forces). The effects are around four times greater for local actors, suggesting that much of the increase in violence in shallow water areas over the past 30 years is due to local actors. It also suggests that conflicts driven by local grievances or tensions within or between specific local communities are more strongly influenced by groundwater availability (Figure 6a). Lastly, whatever the type of violence or actors, there has been a noticeable acceleration of violence after 2010 compared to the pre-2010 period but larger for *low intensity* violence and *local* actors. Understanding these dynamics can provide valuable insights for policymakers and stakeholders in managing and addressing conflicts, particularly at the local level, and in implementing strategies to mitigate the potential negative impacts of groundwater scarcity or inter- and intra-communal disputes (Figure 6b).[6]

Sensitivity analysis. To ensure the robustness of our findings, we conduct an extensive sensitivity analysis using standard exercises commonly found in the literature, as well as specific robustness checks tailored to our research question. Our findings remain largely consistent and robust. Tables related to the different exercises are relegated to Appendix Section OA2. First, we explore

[5] As an alternative measure of conflict incidence, we make use of the richness of the ACLED data to identify conflicts that are likely to be water-related. We thus define "water conflicts" as indicated in the "notes" item or sub-event type category of the ACLED data (see Appendix Section OA0.1 for details). The analysis reveals quantitatively important effects of shallow water over time on water-related violence. In line with anecdotal evidence, these findings point out that, with climate change, cells with shallow water resources are more likely to experience conflict related to water access and disputes over water sources (See Appendix Table OA2.4).

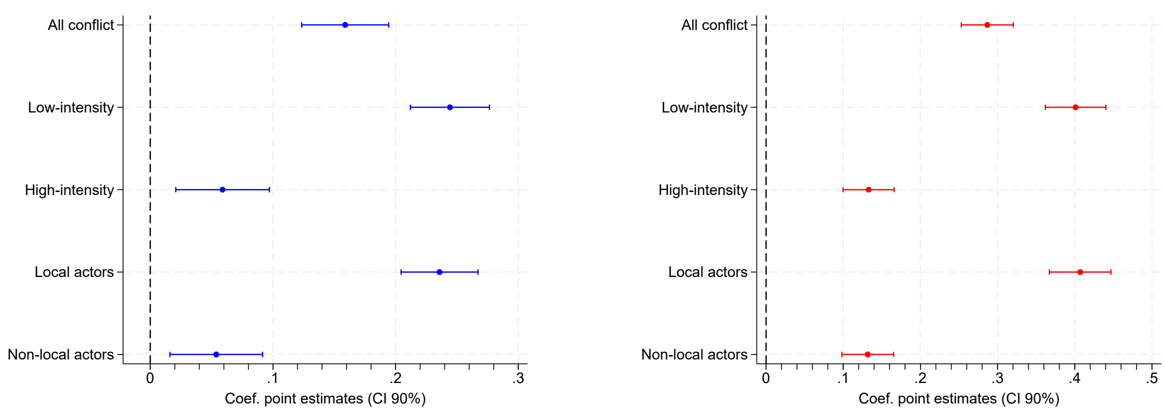
[6] In Figures OA2.2, we display the results from selected non-linear combinations of coefficients of the fractionalization index by nature of violence and actors. Cells with a larger fractionalization index experience more low-intensity violence and violence due to local actors over time, with an acceleration of all types of conflicts after 2010 in areas with higher levels of groundwater access inequality.

Table 2: Average Effects for the Whole Period and Over Time

Dep. Var. : Dummy for conflict	(1) Full period	(2) Diff post/pre 2010	(3) Full period	(4) Diff post/pre 2010
Average effect:				
Shallow water	0.16***	0.29***	0.15***	0.24***
	(0.03)	(0.05)	(0.03)	(0.05)
Frac.			0.05	0.21***
			(0.04)	(0.05)
Obs.	257750	257750	257750	257750
Cell FE	Yes	Yes	Yes	Yes
Country×year FE	Yes	Yes	Yes	Yes

Notes: In all columns, the dependent variable is a dummy taking the value 1 if at least a conflict event is observed in the cell during the year, 0 otherwise. Shallow water refers to the share of 0 to 50 meters deep groundwater. Column (1) and (3) show the nonlinear combination of $\hat{\beta}_t$ for the full period, while column (3) and (4) display the difference of the point estimates for years before 2010 and after 2010. Fractionalization is an index of within cell inequality in access to groundwater, the more diverse the cell is in terms of groundwater levels, the higher the index of fractionalization is. Standard errors clustered at cell level in parentheses. * Significant at 10%, ** significant at 5%, *** significant at 1%.

Figure 6: Type of Events and Actors



(a) Full period

(b) Diff post/pre 2010

Note: Results from selected non-linear combinations of $\hat{\beta}_t$ for the full period (left panel) and differentiating the point estimates for years before 2010 and after 2010 (right panel). Low-intensity is a dummy taking the value 1 if at least one protest and/or riot is observed in the cell during the year, 0 otherwise. High intensity is a dummy taking the value 1 if at least one battle, violence against civilians and/or remote violence event is observed in the cell, 0 otherwise. Local actors is a dummy taking the value 1 if protesters, rioters and/or identity militias are at the origin of at least one event observed in the cell during the year, 0 otherwise. Non-local actors is a dummy taking the value 1 if external forces, political militias, rebel groups and/or state forces are at the origin of at least one event observed in the cell during the year, 0 otherwise. 90% confidence intervals are reported.

alternative measures of groundwater. Instead of defining the share of the cells with water depth ranging from 0 to 50 meters, we define the percentage of the cell with water depth ranging from 0 to 7 meters, 7 to 25 meters, 25 to 50 meters, 50 to 100 meters and 100 to 250 meters (Figures OA2.3 and OA2.4). Second, we saturate the econometric model with admin-1×year FE (Table OA2.2). This demanding level of fixed effects ensures that our effects are not driven by any yearly observed or unobserved admin-1 characteristics. In Table OA2.3, we interact some time-invariant cell specific characteristics that should correlate with both conflict and groundwater with year dummies with the inclusion of i) admin-2×year fixed effects (column 1); ii) the interaction between the Koppen classification dummies with year dummies (column 2)[7]; iii) the latitude and longitude (and their squares) interacted with year dummies to address potential spatial and temporal correlations (column 3); iv) soil fertility and malaria suitability interacted with year dummies (columns 4 and 5); and to ensure that our results are not driven by regions/countries prone to climate change but also where Boko Haram has its own area of influence, we exclude countries such as Nigeria (NGA), Chad (TCD), Niger (NER), and Cameroon (CMR) (column 6). Finally, given the high spatial resolution of the data, and because both conflicts and shallow water are geographically clustered, we allow the error term to be spatially correlated. More precisely, we apply a spatial HAC correction to our standard errors, allowing for both cross-sectional spatial correlation and location-specific serial correlation, following the method developed by Conley (1999) (columns 7 and 8).

3.2 Effects of Local Climate Change

So far, we made the assumption that the impacts of climate change are uniform across cells. However, global climate change affect differently regions in Africa (Trisos et al. (2022)). It is a first-order question to identify the most conflict prone areas, particularly around shallow waters. To this end, we compute a measure of temperature anomalies at the cell-year level that is the yearly temperature deviations from the long term mean of 1961 to 1990 in cell c in the country i at year t between 1997 to 2022. Figure 7 displays for each cell the average temperature anomaly over the period 1997 to 2022. Since 1997, temperatures have been around 0.7 degrees Celsius higher compared to the long-term mean, with individual temperatures anomalies varying on average by 0.23 degrees Celsius from the mean. Dramatically, 11% of cells have experienced a temperature increase of more than one degree since 1997. Then, we compute the moving average of temperature, computed as the average over the years $t-d$ to t, with d taking the values from 0 to 7. When d = 0, it implies that the identification comes from *climate shocks*, while with $d > 0$, it implies that identification comes from longer-run changes in temperatures, which are more likely to capture (permanent) *climate change*.

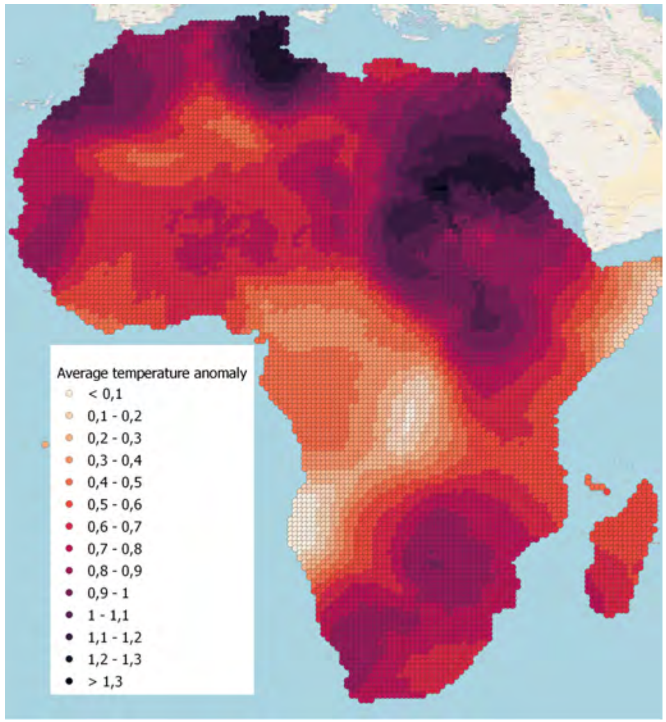
Empirical strategy. To estimate the effect of local climate change, we extend equation (2):

$$Y_{cit} = \beta_1 ShallowWater_c \times Temperature_{cit}^{d=k} + \beta_2 Temperature_{cit}^{d=k} + \theta_c + \theta_{it} + \varepsilon_{cit} \tag{3}$$

where Y_{cit} represents the incidence of violence in cell c, in country i at year t and $ShallowWater_c$ denotes the share of groundwater within the depth range of 0 to 50 meters in cell c. $Temperature_{cit}^{d=k}$ is the moving average of temperature computed as the average over the years $t-d$ to t, with d taking the values from 0 to 7. To account for cell-specific and country×year-specific characteristics, we include a set of fixed effects, θ_c and θ_{it} respectively. Our assumption is that β_1 is positive, indicating that cells with a large share of shallow water become more conflict-prone with an increase in local temperatures.

[7]The Köppen climate classification system uses temperature, precipitation, and vegetation criteria to categorize climates in order to create a comprehensive framework for the classification of global climate patterns.

Figure 7: Average Temperature Anomalies



Note: Average cell level temperature anomaly over the period 1997 to 2022 compared to a long term mean of 1961 to 1990.

Baseline results. Table 3 displays the estimates. Focusing on local *climate shocks*, e.g. temperature in t (d=0), we find that a one standard deviation increase in temperature increases the likelihood of violence by 0.1 standard deviation (Panel A, column 1). However, we do not observe changes in the likelihood of violence based on shallow water availability. When focusing on local *climate change* over a longer time frame (d=2 to 6), cells with more groundwater availability are more prone to violence (columns 2 to 4). In groundwater-rich areas, a one standard deviation increase leads to an increase in conflict from a 0.071 standard deviation (d=2) to 0.276 standard deviation (d=6). This suggests that during periods of intensified and persistent climate change, conflict tends to concentrate in areas with abundant accessible groundwater resources. Likewise, Panel B shows that conflict also increases in areas with higher levels of groundwater inequality ($Frac.$) but only when climate changes are more permanent, i.e., in situations of permanent water stress. The results suggest that conflict increases with temperature in all cells in the short-run. But, when the local shocks are more permanent, temperatures do not affect significantly conflict, except in groundwater-rich areas. As such, when climate changes become more permanent, i.e., in regions experiencing more permanent local climate change, conflict is displaced from all affected cells to the affected cells with more access to groundwater. These latter areas thus become "conflict hotspots" as we will discuss below.

Results by type of violence and actors. Similar to the exercises conducted previously, we leverage the richness of the data on the nature and the actors of violence to estimate the extent to which the persistence of local climate shocks, exacerbated by the availability of shallow water, may vary

Table 3: Local Climate Shocks and Local Climate Change and Conflict

	(1)	(2)	(3)	(4)
Moving average (t-d):	d=0	d=2	d=4	d=6
Panel A				
Shallow Water $\times$ *Temperature*$^{d=k}$	0.002	0.071**	0.179***	0.276***
	(0.018)	(0.029)	(0.035)	(0.036)
Temperature$^{d=k}$	0.104***	0.096***	0.058*	0.008
	(0.016)	(0.026)	(0.033)	(0.035)
Panel B				
Shallow Water $\times$ *Temperature*$^{d=k}$	–0.003	0.051	0.154***	0.247***
	(0.020)	(0.032)	(0.038)	(0.039)
Frac. $\times$ *Temperature*$^{d=k}$	0.023	0.089	0.117	0.135*
	(0.035)	(0.061)	(0.072)	(0.072)
Temperature$^{d=k}$	0.101***	0.083***	0.040	–0.013
	(0.016)	(0.027)	(0.033)	(0.036)
Obs.	257750	257750	257750	257750
Cell FE	Yes	Yes	Yes	Yes
Country×year FE	Yes	Yes	Yes	Yes

Notes: In all columns, the dependent variable is a dummy taking the value 1 if at least a conflict event is observed in the cell during the year, 0 otherwise. Shallow water refers to the share of 0 to 50 meters deep groundwater. *Temperature*$^{d=k}$ is a moving average of temperature, computed as the average over the years $t-d$ to t, with d taking the values 0, 2, 4 and 6. Frac. is an index of within cell inequality in access to groundwater, the more diverse the cell is in terms of groundwater levels, the higher the index of fractionalization is. Cell fixed effects and country×year fixed effects are added in all columns. Standard errors clustered at cell level in parentheses. * Significant at 10%, ** significant at 5%, *** significant at 1%.

depending on conflict types and actors. Note that for the sake of simplicity, we only display the estimates of β_1 considering permanent climate change with d=4 (Figure 8). A number of noteworthy results emerge. First, when climate changes become more permanent it increases conflict in cells with a larger share of shallow water. Quantitatively, a one standard deviation increase by 0.18 standard deviation the level of violence. Second, the effect is mainly driven by *low intensity* violence (protests and riots combined) as *high intensity* violence (battles, violence against civilians, and remote violence) is not significantly correlated with local climate change. Third, permanent climate changes in cells with larger share of shallow water affect *local* actors (protesters, rioters, and identity militias), while we fail identifying an effect on non-local actors. Lastly, with permanent climate change, cells with a larger share of shallow water experience more water related conflict events (Appendix Table OA3.7).

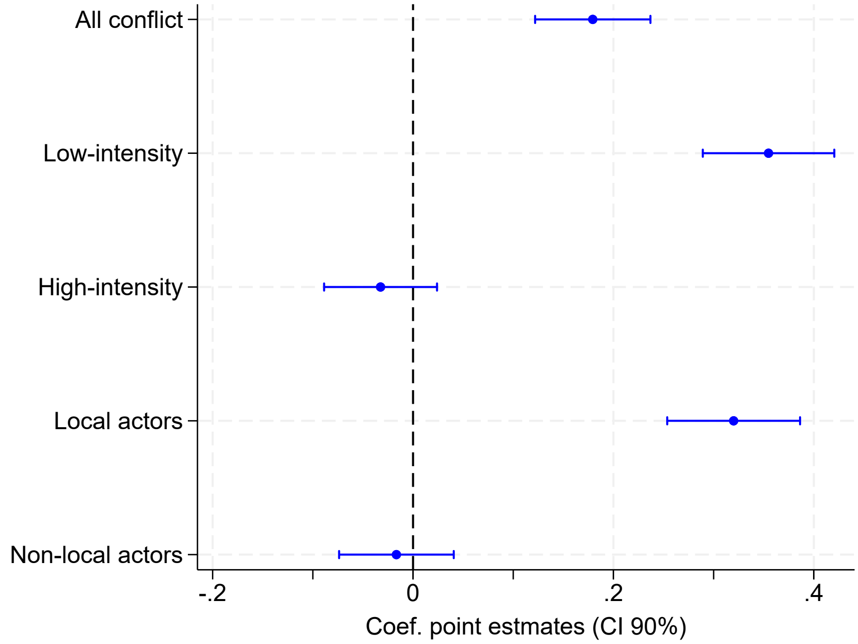
Sensitivity analysis. In Online Appendix Section OA3, we replicate the sensitivity analysis from Section 3.1 but in the context of the local climate change. Across the different exercises, our results remain largely unchanged both in terms of magnitude and statistical significance.

4 Investigating the Mechanisms and Identifying Violence Hotspots

4.1 Mechanisms

The previous results were already informative on the mechanisms as the effect were stronger for low-intensity conflicts, local actors and local violence. In this section, we go a step further by analyzing whether we can identify mechanisms driving our results. Coming back to our conceptual framework in the introduction, with climate change, the *income effect* (opportunity cost) should

Figure 8: Local Climate Change, Shallow Water, and Conflict



Notes: Results from β_1 considering climate change with d=4 are reported. Low-intensity is a dummy taking the value 1 if at least one protest and/or riot is observed in the cell during the year, 0 otherwise. High intensity is a dummy taking the value 1 if at least one battle, violence against civilians and/or remote violence event is observed in the cell, 0 otherwise. Local actors is a dummy taking the value 1 if protesters, rioters and/or identity militias are at the origin of at least one event observed in the cell during the year, 0 otherwise. Non-local actors is a dummy taking the value 1 if external forces, political militias, rebel groups and/or state forces are at the origin of at least one event observed in the cell during the year, 0 otherwise. 90% confidence intervals are reported. Cell fixed effects and country$\times$year fixed effects are added in all regressions.

reduce conflict in groundwater-rich areas (since having water is more valuable). At the same time, the *prize effect* should increase conflict incidence in groundwater-rich areas given that water is becoming scarcer (hence, more valuable). Our results suggest that the prize effect dominates the income effect in the Sub-Saharan African context.

Note that we suggest two potential mechanisms but that do not preclude other mechanisms to matter too. First, the effects could vary depending on group or local characteristics. In the Sub-Saharan African context, groundwater is rarely used for irrigation. Instead, it is used to increase drinking water supply, whether for humans or livestock. As such, a prediction is that the effects should be stronger in areas specialized in pastoral activities where the prize effect is increased because of the water's value for livestock herders and their livestock. In addition, the concentration of conflict in groundwater-rich areas assumes that actors engaged in conflict can easily move/travel to such areas from other areas. Livestock herders are far more mobile than farmers because they can move with their "capital". Also, livestock herder communities tend to be more militarized because they are more organized against livestock theft. Therefore, we might expect stronger effects on conflict, especially high-intensity conflicts, in regions specialized in pastoral activities. Likewise, we may expect more conflict in areas where livestock herders move more often in the dry season, which tend to be areas where farmers grow crops. The mobility and presence of herders is indeed typically driven by the availability of water, forage, and other environmental conditions. McGuirk and Nunn (2020) show that droughts within the territory of transhumant pastoralists have a direct impact on increasing conflict in adjacent areas. Below, we thus consider a cell-level measure of transhumant pastoralism as well as a measure of proximity to the "border" between farming and livestock herder communities.

In addition, the likelihood that conflict arises in some regions depends on the state's ability to control those regions. As Döring (2020) explains, when state presence is weak, communities may be more prone to rely on violence against other groups trying to use their water points or seize water points from other communities. At the same time, low-intensity violence (protests and riots) are more likely when the state is present, since the goal of the low-intensity violence is to put more pressure on local authorities so that they focus on their needs. Below, we thus use proximity to national or regional capitals in order to investigate if local state capacity can mitigate water-related conflict. To add a broader measure of state capacity to this analysis, we employ an index built by Agneman et al. (2022) to approximate local state capacity combining a survey-based approach and a number of variables reflecting the states' territorial reach.

Empirical strategy for global climate change. We estimate the following equation:

$$
\begin{aligned}
Y_{cit} = & \sum_{t=1998}^{2022} \beta_t Shallow\,Water_c \times Mechanism_c \times \mathbb{I}_t \\
& + \sum_{t=1998}^{2022} \alpha_t Shallow\,Water_c \times \mathbb{I}_t + \sum_{t=1998}^{2022} \gamma_t Mechanism_c \times \mathbb{I}_t + \theta_c + \theta_{it} + \varepsilon_{cit}
\end{aligned}
\tag{4}
$$

where, Y_{cit} represents the incidence of violence. The variable $ShallowWater_c$ denotes the share of the cell with groundwater availability ranging from 0 to 50 meters deep. The variables of mechanisms $Mechanism_c$ denotes alternatively: (i) a measure of transhumant pastoralism in the cell c; (ii) a measure of the combined presence of herders and farmers in the cell (i.e., of the "border" between these two types of communities); (iii) measures of the proximity to the national capital or the closest regional capital, which we compute as the negative of the log Euclidean distance from the cell centroid to the selected capital; and (iv) the index of local state capacity.

The term $\mathbb{I}_t$ represents year dummies, allowing for the examination of the non-linear time-varying relationship between groundwater availability, the different mechanisms, and conflict. Additionally, the terms θ_c and θ_{it} capture cell fixed effects and country×year fixed effects, respectively (accounting for unobserved factors specific to each cell and country×year). We estimate equation 4 using a linear probability model (LPM) and standard errors are clustered at cell level. Our interest lies in the coefficients β_t that capture the triple interaction effect of groundwater availability, depending on the level of each mechanism, in each specific year t, estimated relative to the omitted year 1997.

Empirical strategy for local climate change. To estimate the interacted effect of local climate change and the mechanisms, we specify the following equation:

$$
\begin{aligned}
Y_{c,i,t} = {} & \beta_1 Shallow\,Water_c \times Mechanism_c \times Temperature_{cit}^{d=k} \\
& + \beta_2 Shallow\,Water_c \times Temperature_{cit}^{d=k} + \beta_3 Mechanism_c \times Temperature_{cit}^{d=k} \\
& + \beta_4 Temperature_{cit}^{d=k} + \theta_c + \theta_{i,t} + \varepsilon_{c,i,t}
\end{aligned} \tag{5}
$$

where, $Y_{c,i,t}$ represents the incidence of violence and $Shallow\,Water_c$ denotes the share of groundwater within the depth range of 0 to 50 meters in cell c. The variable $Mechanism_c$ which denotes the mechanisms. $Temperature_{cit}^{d=k}$ is the moving average of temperature computed as the average over the years $t-d$ to t, with $d=4$ for a sake of simplicity. We include cell-specific (θ_c) and country$\times$time-specific ($\theta_{i,t}$) fixed effects.

Pastoralism Results. Conflicts between farmers and herders have escalated globally, notably in the Sahel region, as climatic stress intensifies competition over dwindling resources. Anecdotal evidence suggests that economic threats caused by drought compel nomadic groups to encroach on traditional territories, sparking violent clashes with sedentary communities and underscoring the significant role of climate-related factors in fostering conflict (McGuirk and Nunn, 2020; Eberle et al., 2020). We use their respective measures of transhumant pastoralism and of the combined presence of herders and farmers (capturing the "border") in the cell.

Figure 9 displays the non-linear combinations of $\hat{\beta}_t$ estimated from equation 4 and Figure 10 displays β_1 estimated from equation 5. The conflict-groundwater relationship is accentuated in pastoral cells. This is part due to an intensification of low-intensity conflicts. However, high-intensity conflicts are also more likely in such areas, possibly due to their higher degree of militarization. Pastoral groups are indeed larger and less local than farming groups. Remarkably, similar effects are obtained for the measure of proximity to the farmers-herders border (Figures 11 and 12). There is more conflict along all dimensions. Policy-wise, this suggests that climate change leads to more conflict in groundwater-rich areas in pastoral regions. As pastoral regions tend to be more remote and less sparsely populated and as pastoral groups tend to be more marginalized in the national political process, there is a risk that such regions become a fertile ground for separatist or terrorist groups, as is currently observed in the Sahel.

State Capacity Results. We first use the proximity to a regional capital or a national capital (c. 2010). Being located closer to a capital could indicate military and police presence and better governance, and hence reduce conflict. However, military and police presence could also increase conflict, and fighting groups may be more interested in controlling state resources, actually leading to more conflict in areas with more state presence. Overall, the findings suggest that being close to a regional capital does not exacerbate nor reduce the link between climate change and conflict (Figures 13 and 14). That may not be surprising as regional capitals are particularly "weak" in the sub-Saharan African context. Power indeed tends to be overly concentrated in the largest/capital city in most countries. Interestingly, the proximity to a national capital has more ambiguous effects (Figures 15 and 16). Overall conflict incidence appears unchanged. But the nature of conflict is modified. Closer to the capital city, we observe more low-intensity conflicts, and less high-intensity conflicts. Indeed, in more central areas dominating the national political process, protests and riots might be more efficient at swaying the state to obtain resources. Furthermore, the state is stronger

Figure 9: Transhumant Pastoralism, Avg. Effect

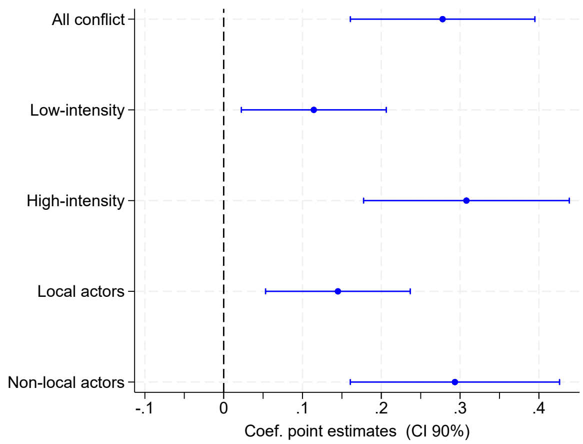
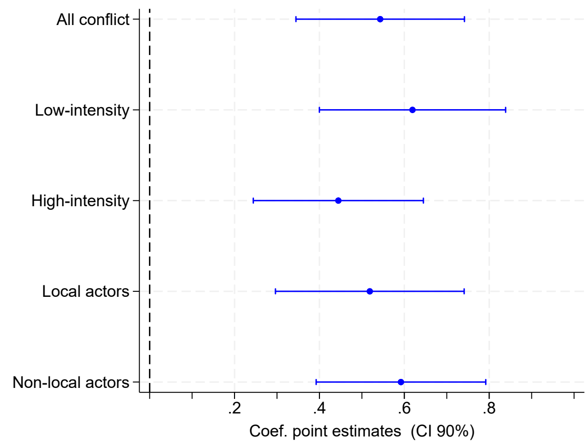


Figure 10: Transhumant Pastoralism, Tmp MA



Results from the selected non-linear combinations of the triple interaction between a measure of transhumant pastoralism, the share of shallow water and the $\hat{\beta}_t$ are displayed on the left graph. Results from the triple interaction between a measure of transhumant pastoralism, the share of shallow water and the measure of climate change are displayed on the right graph. All conflict is a dummy taking 1 if at least one conflict event is observed in the cell during the year, 0 otherwise. Low-intensity is a dummy taking the value 1 if at least one protest and/or riot is observed in the cell during the year, 0 otherwise. High intensity is a dummy taking the value 1 if at least one battle, violence against civilians and/or remote violence event is observed in the cell, 0 otherwise. Local actors is a dummy taking the value 1 if protesters, rioters and/or identity militias are at the origin of at least one event observed in the cell during the year, 0 otherwise. Non-local actors is a dummy taking the value 1 if external forces, political militias, rebel groups and/or state forces are at the origin of at least one event observed in the cell during the year, 0 otherwise. 90% confidence intervals are reported.

Figure 11: Farmer-Herders Border, Avg. Effect

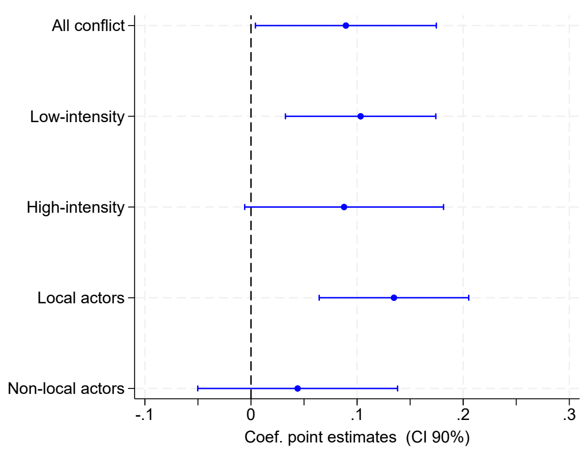
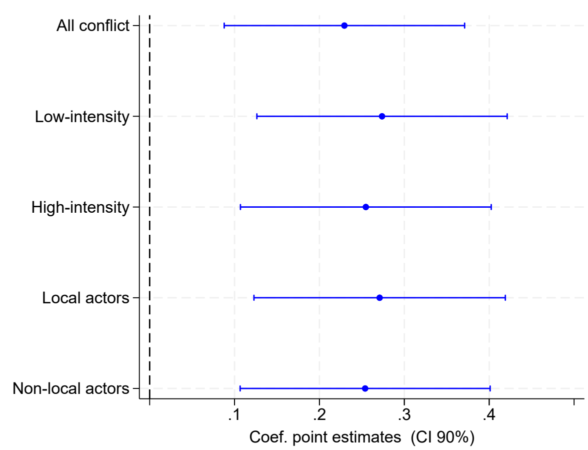


Figure 12: Farmer-Herders Border, Tmp MA



Results from the selected non-linear combinations of the triple interaction between a measure of farmer-herder presence, the share of shallow water and the $\hat{\beta}_t$ are displayed on the left graph. Results from the triple interaction between a measure of farmer-herder presence, the share of shallow water and the measure of climate change are displayed on the right graph. All conflict is a dummy taking 1 if at least one conflict event is observed in the cell during the year, 0 otherwise. Low-intensity is a dummy taking the value 1 if at least one protest and/or riot is observed in the cell during the year, 0 otherwise. High intensity is a dummy taking the value 1 if at least one battle, violence against civilians and/or remote violence event is observed in the cell, 0 otherwise. Local actors is a dummy taking the value 1 if protesters, rioters and/or identity militias are at the origin of at least one event observed in the cell during the year, 0 otherwise. Non-local actors is a dummy taking the value 1 if external forces, political militias, rebel groups and/or state forces are at the origin of at least one event observed in the cell during the year, 0 otherwise. 90% confidence intervals are reported.

in more central areas, making it costlier to engage in high-intensity conflicts.[8]

Figure 13: Distance to Regional Capital, Avg. Effect

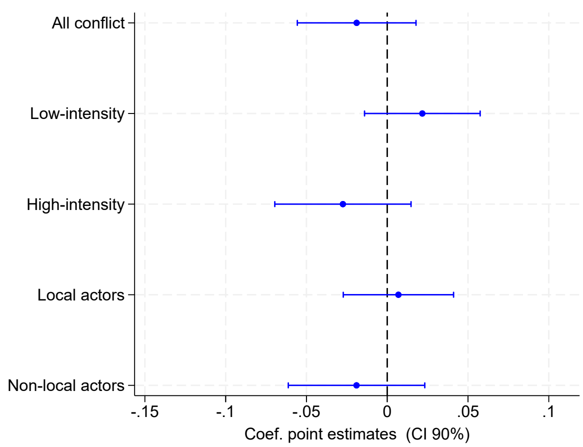
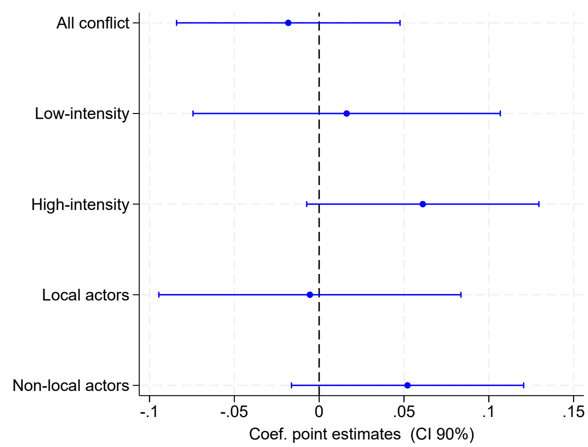


Figure 14: Distance to Regional Capital, Tmp MA.



Results from the selected non-linear combinations of the triple interaction between a measure of proximity to a regional capital, the share of shallow water and the $\hat{\beta}_t$ are displayed on the left graph. Results from the triple interaction between a measure of proximity to a regional capital, the share of shallow water and the measure of climate change are displayed on the right graph. All conflict is a dummy taking 1 if at least one conflict event is observed in the cell during the year, 0 otherwise. Low-intensity is a dummy taking the value 1 if at least one protest and/or riot is observed in the cell during the year, 0 otherwise. High intensity is a dummy taking the value 1 if at least one battle, violence against civilians and/or remote violence event is observed in the cell, 0 otherwise. Local actors is a dummy taking the value 1 if protesters, rioters and/or identity militias are at the origin of at least one event observed in the cell during the year, 0 otherwise. Non-local actors is a dummy taking the value 1 if external forces, political militias, rebel groups and/or state forces are at the origin of at least one event observed in the cell during the year, 0 otherwise. 90% confidence intervals are reported.

4.2 Past and Future Violence Hotspots

Our results highlight the important contribution of climate change to the spread and intensification of violence in Africa since 1997, particularly in "hot" cells with a high proportion of shallow water. In the following, we consider two exercises. First, over our period of interest (1997-2021), the mean temperature has increased by around 0.4 degrees in comparison to the 1990-1996 period mean (Harris et al. (2020)). What has been the contribution of this positive trend in temperature on observed conflicts in Africa? Figure 17 displays by cell the predicted decrease in the conflict probability that would be observed in 2021 if the temperature were the same as the median level of temperature over the period 1990-1997. This counterfactual exercise is based on the estimated coefficients of equation 3 (with d=4, Table 3, Panel A column 3). The effect is heterogeneous across cells. In cells without shallow water the absence of positive trend in temperature the probability of observing conflict would have been 1% lower. But, in cells with a proportion of shallow water larger than 50%, the likelihood would have been reduced by 7%. Interestingly, in

[8] Alternatively, we make use of a more broadly measure of state capacity. Agneman et al. (2022) predict local state capacity in Sub-Saharan Africa through machine learning model using a large set of inputs such as satellite imagery, infrastructure data, and Afrobarometer survey. In our context, local state capacity has similar effects to proximity to the national capital (Online Appendix Section OA4, Figures OA4.5 and OA4.6).

Figure 15: Closeness to National Capital, Avg. Effect

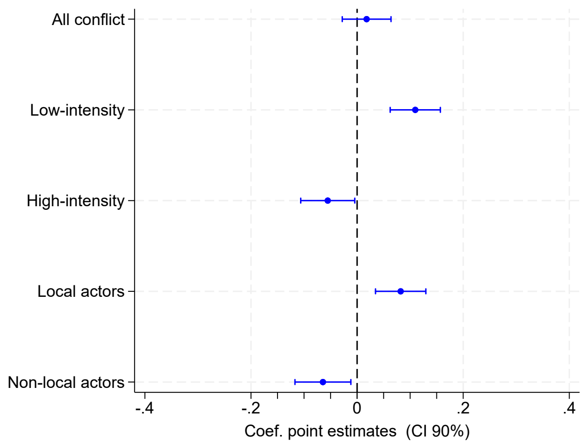
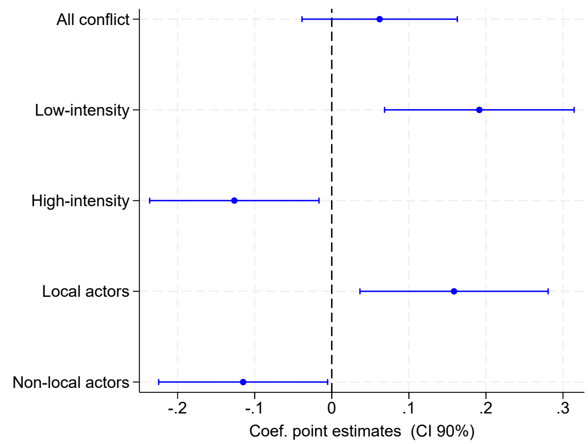


Figure 16: Closeness to National Capital, Temp.



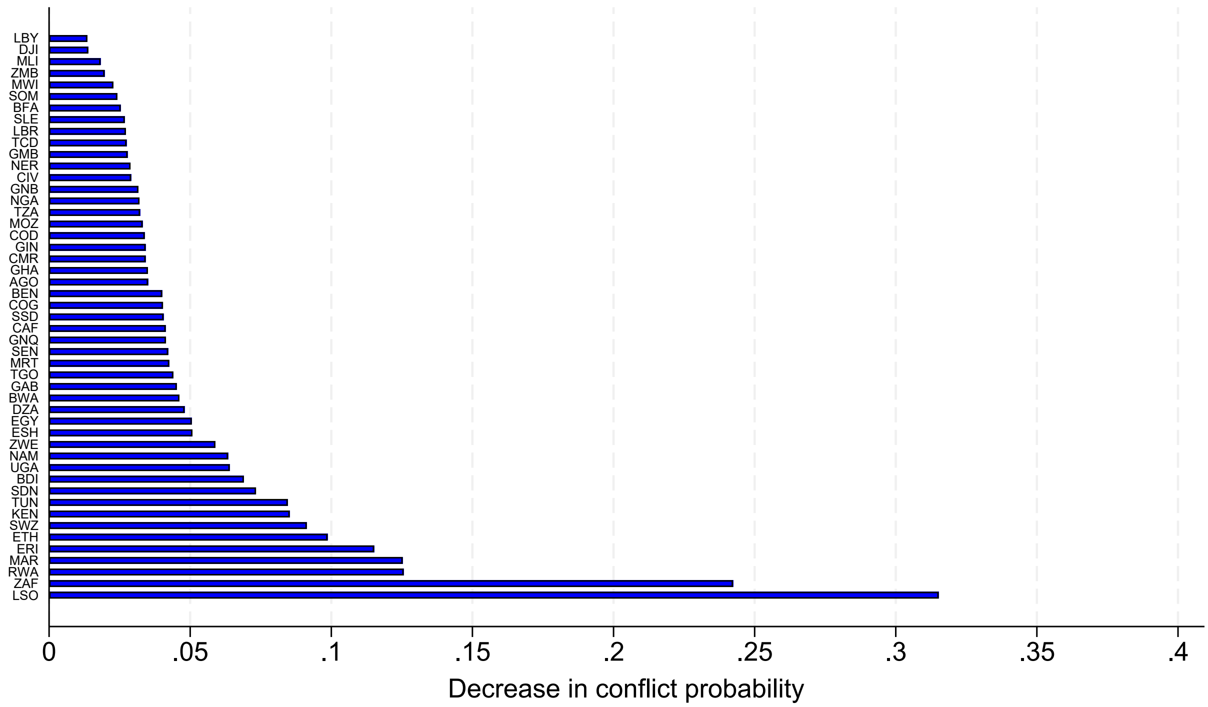
Results from the selected non-linear combinations of the triple interaction between a measure of proximity to a national capital, the share of shallow water and the $\hat{\beta}_t$ are displayed on the left graph. Results from the triple interaction between a measure of proximity to a national capital, the share of shallow water and the measure of climate change are displayed on the right graph. All conflict is a dummy taking 1 if at least one conflict event is observed in the cell during the year, 0 otherwise. Low-intensity is a dummy taking the value 1 if at least one protest and/or riot is observed in the cell during the year, 0 otherwise. High intensity is a dummy taking the value 1 if at least one battle, violence against civilians and/or remote violence event is observed in the cell, 0 otherwise. Local actors is a dummy taking the value 1 if protesters, rioters and/or identity militias are at the origin of at least one event observed in the cell during the year, 0 otherwise. Non-local actors is a dummy taking the value 1 if external forces, political militias, rebel groups and/or state forces are at the origin of at least one event observed in the cell during the year, 0 otherwise. 90% confidence intervals are reported.

cells without water fractionalization, the probability of observing conflict would have been 1% lower. Conversely, for the highest percentile of fractionalization, the likelihood of observing conflict would have been reduced by 14%. In Figure 18 we display by country the average decrease in conflict probability if temperature had remained constant since the 1990s.

Finally, the richness of our model also allows us to give an indication, in view of the projections on the temperature trend in the coming decades, of what the variations in the probability of violence would be. To do this, we consider local temperature predictions for the period 2060-2080 (World Bank's Climate Change Portal Knowledge (CCPK)) to predict future hotspots for water-related conflicts.[9] For each cell, we predict the future probability of experiencing conflict by taking the predicted median temperature between 2060 and 2080 and interacting it with our baseline estimated coefficient of the share of shallow water (0-50m) and temperature (d=4) from Table 3 Panel A column (3). A simple visual representation of prediction highlights the growth in violence across most of sub-Saharan Africa but with a large heterogeneity (Figure 19). The Sahelian and Horn of Africa regions are those for which the probability of violence will experience the greatest increase.

[9]We use the median value for annual mean surface air temperature derived from CMIP6 climate models. The data covers the period from 2060 to 2080 under the Shared Socioeconomic Pathway 5-8.5 scenario.

Figure 17: Country-level decrease in conflict probability



Country level decrease in conflict probability in counterfactual exercise.

5 Conclusion

TBD – Remi Due to climate change, water is becoming an increasingly scarce resource, thus making groundwater access a highly relevant policy issue. By using a cell-year panel data set covering the period 1997-2021 for sub-Saharan Africa, we are able through multiple exercises to investigate the relationship between groundwater level, climate change, and conflict. To do so, we combine data on groundwater depth, from which we extract a measure of the share of shallow water in each cell, as well as an index of within-cell inequality in access to water, with geolocalized data on conflict events. We use three empirical analyses to uncover various aspects of the research question.

Firstly, we explore through a simple cross-sectional analysis whether shallow water-rich areas experienced more, or less, conflict during our period of study. Secondly, we study the impact of global climate change, affecting the entire continent during the same period, on the relation between groundwater and conflict. Thirdly, we examine the association between conflict and groundwater in areas experiencing local climate shocks or long-term climate changes over time.

In a last exercise, drawing on anecdotal evidence and studies highlighting that water access and gender inequality are closely inter-related, we use individual data on gender-based violence to estimate the relationship between water-related factors and violence against women. We find in our main cell-level analyses that areas with a higher share of shallow water are more prone to violence, whether we focus on global climate change or local climate change.

More precisely, our results display a pronounced effect on low-intensity events such as protests

Figure 18: Decrease in conflict

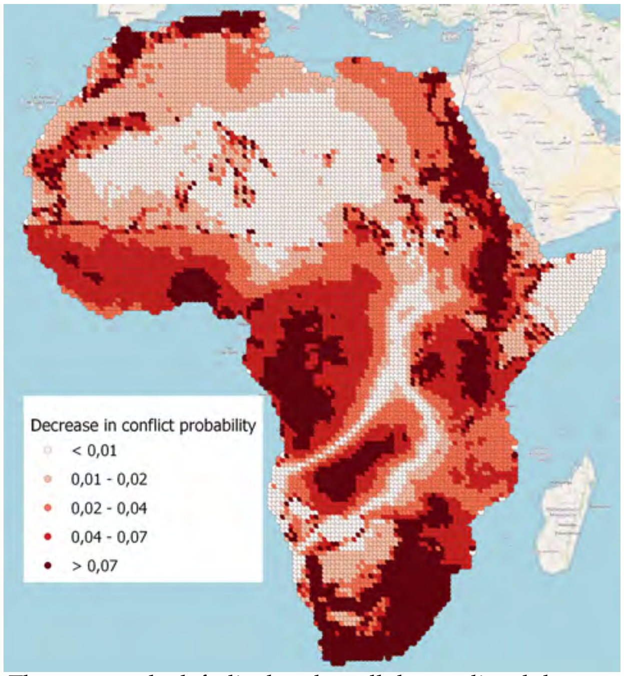
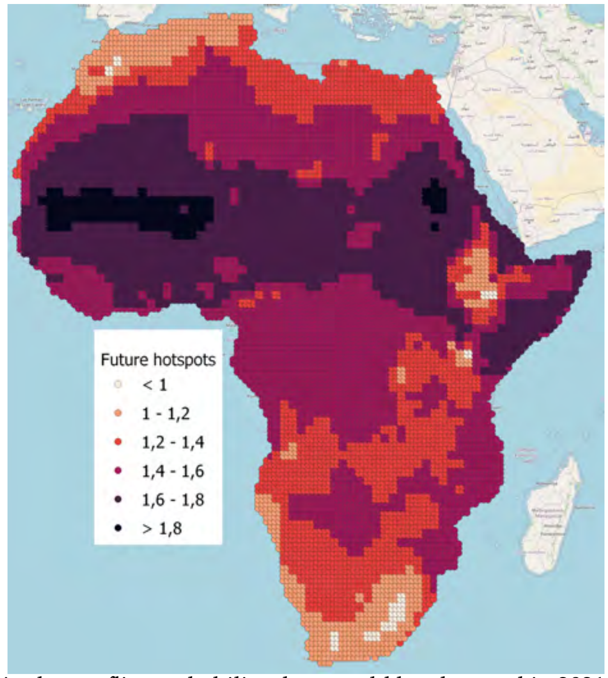


Figure 19: Hotspots of violence 2060-2080



The map on the left displays by cell the predicted decrease in the conflict probability that would be observed in 2021 if the temperature were the same as the median level of temperature over the period 1990-1997. The map on the right displays by cell the predicted future hotspot for water-related conflicts.

and riots, as well as a significant role of local actors (protesters, rioters, and identify militia activists) who operate at a local level for objectives often related to natural resources. We also highlight the role of inequality in access to groundwater in driving water-related conflict.

Lastly, our results show that women in charge of fetching water are more exposed to physical violence from their partner. The results also suggest that there is a correlation with the distance to reach the water source in women's experience of sexual violence.

This study helps more broadly understand the relationship between water access and conflict, and contributes to our knowledge of the mechanisms by which climate change will impact sub-Saharan Africa in the future. The focal point of discussions should revolve around policies that encourage the sustainable use of groundwater, in order to prevent frictions. We highlight the importance of improving groundwater access, in a way that inter-communal inequality is not reinforced. The gender overview of our analysis also highlights the importance of access to safe water for women to account for how differently water scarcity can affect women.

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